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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 190

Contribution from the Office of Experiment Stations
A. C. TRUE, Director

Washington, D. C. ▼ April 24, 1915

THE DRAINAGE OF IRRIGATED LAND

By

R. A. HART, Supervising Drainage Engineer

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INTRODUCTION.

It is now generally recognized that irrigated land may become waterlogged and impregnated with harmful mineral salts, and that drainage must be the means of the reclamation of land so affected. Already, in the United States, more than 10 per cent of the entire area that has been irrigated for any considerable period is either absolutely unproductive or is given over to the less valuable crops or to poor pastures; while even in the most recently developed irrigation projects serious injury is being wrought. These injured lands are to be found in all the arid and semiarid States and in practically every valley where irrigation is a factor in the agricultural development.

The feasibility of reclaiming these waterlogged and alkali lands has been demonstrated in numerous experiments, and methods have been developed by which the work can be done effectively and economically. It is the purpose of this bulletin to present in concise form the fundamental principles upon which the reclamation of such land is based, to describe typical conditions and the best methods of treating them, and to give practical advice as to actual operations.

Note.—The information in this bulletin is intended for drainage engineers and landowners of the arid West. It is not applicable to the humid section of the United States.

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Drainage practice in the arid section differs greatly from that in the humid region. The nature of the land requiring drainage is different, and the methods applied are unlike those employed in the humid section. In fact, there is little in common between the two situations, and drainage experience in the humid section avails little in dealing with the problems of draining irrigated lands. For this reason literature on the general subject of drainage should be used with caution, as the difference in conditions between the arid and humid regions has been clearly recognized only within the last few years.

MANIFESTATIONS OF POOR DRAINAGE CONDITIONS.

Injury wrought by overirrigation manifests itself in several ways. In some cases the lands are literally swamped, and ponds, bogs, and tule marshes are dominant features. In others the ground is merely waterlogged, and the injury is shown by the wet condition of the soil, by the presence of alkali salt crusts on the surface of the higher spots of ground, and by any vegetation that may have survived the inhibitive conditions. Very often, however, there is no visible sign of wetness, and the only marks of the injury are the incrustations of alkali salts, the presence of highly alkali-resistant plants, or the absence of all vegetation in the worst-affected areas.

SPECIFIC OBJECTS OF DRAINING.

It is important, at the outset, to understand the specific results which it is proposed to accomplish by draining. These may briefly be stated as follows: (1) To lower the ground-water table to such a depth that the moisture and air conditions within the root zone are properly balanced; (2) to provide an outlet for percolating water, so that fluctuations of the ground-water table within the root zone will be prevented; (3) to effect rapid removal of the excess moisture resulting from spring thaws; and (4) to provide an outlet for the downward moving water used to dissolve out the injurious salts.

PRELIMINARY INVESTIGATIONS.

NECESSITY FOR KNOWLEDGE OF CONDITIONS.

Having in mind the above-mentioned objects of draining, it is clear that the existing conditions must be known before work is commenced, and that the system must conform to these conditions. Random procedure is manifestly poor policy where the objects aimed at are so definite. A little study and the application of judgment will often indicate how the drainage may be satisfactorily accomplished at comparatively small cost. On the other hand, it is quite possible, in the irrigated section, to install a system having many more lines than are necessary, and still meet with total failure. There are few projects so small and apparently so simple as not to warrant the

employment of one trained in this work to make the preliminary studies and to design the system. From a drainage standpoint, the average landowner rarely has any extensive knowledge of the conditions on his farm, especially of those beyond the plow depth, which latter are, in this form of reclamation, of the highest importance.

SOURCE AND AMOUNT OF DAMAGING WATER.

The most important factors affecting the design of a system of drainage for irrigated land are the source and movement of the damaging water. The water does not come directly from precipitation, as is the case in humid regions, although precipitation may have a bearing on the problem and may need to be considered. Percolating irrigation water usually is the cause of the injury, and this may have its movement *downward* through the soil of the tract being irrigated, *laterally* through pervious strata extending back under higher lands, or *upward* from pervious strata having considerable depth and connecting with distant sources at a higher elevation. Under the latter conditions the water is under pressure. The water may represent waste from the irrigation of the injured tract itself, adjacent lands, or distant lands; again, it may represent direct loss from irrigation ditches, laterals, canals, and reservoirs. In any case, a successful drainage system can not be designed until the source of the damaging water is known, and until the movement of the underground water has been studied.

The most difficult problem in connection with the drainage of irrigated lands is the determination of the quantity of water that will be developed and for which it will be necessary to provide an outlet. For tracts up to a few hundred acres in area and having average soil and subsoil, the simplest method, and one which has proved reliable, is to determine the irrigation supply and to provide a drainage capacity of one-third that amount of water. As the size of the tract increases, however, this coefficient should be decreased. If the subsoil be clay, provision for one-fifth the irrigation supply will suffice for small tracts. In areas of a square mile or more, it is usually sufficient to provide for a run-off of from $1\frac{1}{4}$ to $2\frac{1}{2}$ cubic feet per second for each square mile, depending upon the porosity of the soil and the duty of the irrigation water.

The foregoing bases do not apply to the drainage of lands underlain by gravel. In such lands it is the area that is contributing the damaging water, not the area to be drained, that must be taken into consideration. Oftentimes the drainage discharge from gravelly lands is several times greater than the irrigation supply of the injured tract.

If the height of the ground-water table be variable, it is possible to make a close estimate of the necessary capacity by ascertaining

the average *dangerous* rise throughout the season and the approximate percentage of void spaces in the soil. From these data the daily run-off that must be provided for may be computed.

Another method of determining the required capacity is to ascertain the maximum height of the water table above the required drainage depth, and to determine the approximate percentage of void spaces in the soil. Then, assuming the number of days in which it is required to remove the calculated volume of water, the daily run-off may be determined. If the ground water be always at the surface, the same system may be employed, but the evaporation and any surface run-off that occurs must be taken into consideration.

TOPOGRAPHY AND SOIL.

The required capacity of a drainage system can not be reliably determined without an accurate survey and a careful study of the soil and subsoil. The survey should be made to ascertain the amounts and directions of slope, the locations of natural and artificial features that may influence the design of the system, and the dimensions of the tract as a whole and as to its various classified portions. The subsurface examinations should yield information as to the nature of the soil, its stratification, its water-carrying capacity, and its capillary power.

From the data thus obtained, the proper location, frequency, and depth of drains may be determined, after which the sizes of the various units may be ascertained by reference to the required capacity.

OPEN CANALS.

In the design of an open canal the important points to be considered are the effectiveness of the drain, its carrying capacity, its mechanical construction, and its maintenance in good condition.

Experience has taught the necessity of providing considerable depth. This should never be less than 6 feet, presuming that the maximum depth of flow will be 1 foot, and 8 feet would be a better minimum. Thus, as is shown in figure 1, the cross section of stream flow is small as compared with the cross section of the canal itself. The side slopes are quite flat; they never should be steeper than 1 horizontal to 1 vertical, and it is sometimes necessary to make them as flat as 3 horizontal to 1 vertical.

A berm of not less than 6 feet should be left on either side of the canal and the spoil should be banked up on one or both sides. The spoil should not be scattered over the adjacent farms for a number of years, at least, as it is "dead" material and will do injury to the soil. The spoil banks are useful in keeping waste water and storm water from entering the drain directly and injuring the channel. All of the spoil may be placed on one side if it is desired that a roadway run parallel with the drain.

The size of drain required depends upon the amount of water to be carried, the slope of the canal, the condition of the channel, and the shape of the cross section of the flowing water. All of these factors influence the velocity of flow, which should be low enough to prevent erosion and yet high enough to prevent silting and the growth of vegetation. The desired velocity controls, to a large extent, the values that should be given the foregoing factors. Average soils will stand a velocity of 3 feet per second, and a velocity of 2 feet per second will prevent the growth of vegetation and the deposition of silt. The slopes required to give these velocities vary from one-half foot per mile in very large canals to a number of feet per mile in the case of small laterals. In general, if the ratio of the depth of flow to the cross section of flow be small, greater slope will be necessary or permissible.

Laterals or farm drains of just the right capacity to care for the water would be too small for economical construction. Furthermore,

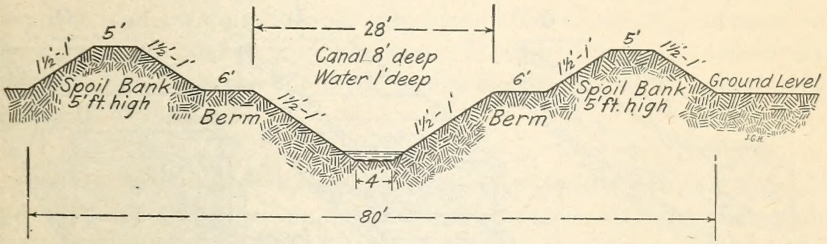

FIG. 1.—Ideal cross section of open canal in medium soils, showing relation between sectional areas of stream and canal.

a small amount of material falling into such drains would seriously obstruct them. It is therefore considered good practice to give open ditches a minimum bottom width of 4 feet, except in very stiff, homogeneous clay, where it may be 3 feet.

COVERED DRAINS.

LUMBER BOX DRAINS.

Lumber box drains are chiefly employed in isolated places where transportation rates are so high as to make the cost of tile prohibitive; their greatest advantage is, perhaps, their cheapness. This advantage disappears, however, in localities near tile factories. Another advantage of such conduits is that the boxes may be laid in comparatively long sections, which afford a more stable bearing and make for a more uniform channel. The life of such a conduit is reasonably long if the lumber is always wet, but where alternate wetting and drying take place the material may fail in a few years. The presence of alkali salts seems to be beneficial rather than injurious to the wood, but sodium sulphate destroys the nails in a very short time. It is necesary, therefore, so to construct the boxes that their integrity of form

does not depend upon the nailing. Under ordinary conditions the soil becomes compacted within a few months after installation, so that the boxes hold together, although the nails may have been eaten entirely away. Boxes are less liable to displacement than are tile, but if the ground is very mushy it is difficult to lay the former before caving takes place. Boxes are also the more likely to be buoyed upward by the fluid soil, but on the other hand it is often necessary to lay planks under tile to maintain grade and line, a precaution which is unnecessary in the case of boxes. On the whole, however, it may be said that lumber boxes should not be used where tile is available at a comparable price.

In no case should a triangular or V-shaped box, or an open-bottom box be employed.

The simplest form of lumber box drain is shown in figure 2, *a*. The lumber runs the long way of the box and the sections may be as long as 16 feet if the soil conditions warrant. If the ground tends to cave,

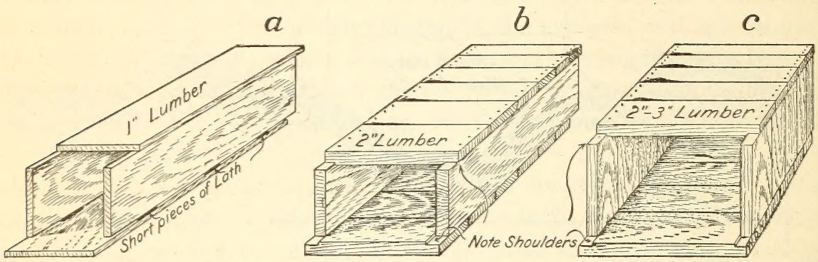

FIG. 2.—Types of lumber box drains.

shorter sections should be employed. The top is nailed tightly to the sides, but the bottom is separated from the sides by short pieces of lath placed at intervals of 2 or 3 feet. The slit thus left provides for the entrance of the water. In soft ground the slit should be protected against the entrance of silt and sand by a gravel or cinder filter. One-inch lumber may be used for boxes up to 8 inches in width, and 2-inch lumber for boxes up to 12 inches in width. For somewhat larger boxes the lumber should run crosswise, as shown in figure 2, *b*. It is a convenient arrangement to employ 2 by 12 inch planks for the sides and to have the top and bottom pieces cut to the proper length. These should be milled, as shown, to afford shoulders which will hold the box together after the nails are destroyed. One-inch material may be used for the bottoms, except in soils so fluid that an upward pressure is exerted. The top pieces should fit tightly together but the bottom pieces should be separated from one-fourth to one-half inch to provide for the entrance of the water. Such boxes should not be over 24 inches in width.

For still larger sizes, 3-inch material should be used and the side planks should be wider. It is not advisable to use lumber over 16

inches in width, however, nor to make the sides from two widths cleated together. For the larger sized box drains, it is best to build the box in short sections as shown in figure 2, *c*. This type of conduit is especially useful in bad ground, as it may be laid in much the same manner as tile. The lumber should be milled to provide shoulders. The sections should interlock, as shown in figure 2, *c*. These shoulders may be easily and cheaply cut by passing each end of the top and bottom pieces over a circular saw, the latter being so set as to cut out a rabbet as deep as the thickness of the saw and as wide as the thickness of the side planks.

CEMENT TILE.

The use of cement tile has occasioned much discussion, owing to the failure of lean, improperly-made tile. However, even the best of cement tile is open to suspicion where sodium or magnesium sulphates are present in the soil. Cement tile should be made very rich, usually not leaner than 1:2:4; the materials should be well gauged, mixed very wet, and carefully tamped into form, after which the tile must be properly cured, preferably by steam. These requirements absolutely eliminate hand-tamped tile made so dry that they may be taken from the forms at once.

CLAY TILE.

Clay tile, when properly made of suitable materials, are very durable and may be depended upon, however strongly alkaline the drain water may be. They should be vitrified and as impervious as possible; the walls should be smooth and of fairly uniform thickness; the bore should be cylindrical and the ends smooth. There should be no serious cracks or blisters, and the content of foreign material should be small. Lime, especially, should be avoided. The tiles usually come in lengths of either 1 or 2 feet in the smaller sizes, and 3 feet in the larger sizes. Under ordinary circumstances the 2-foot length is preferable for the smaller sizes, as tiles of this length are more easily handled and keep their positions better, while sufficient inlet area is afforded by the 2-foot spacing of joints. The walls should be sufficiently thick to give the tile the strength necessary to withstand the pressure of the saturated earth.

SIZE OF CONDUIT.

The carrying capacity of a tile drain depends upon the diameter of the tile, the slope of the drain, the accuracy with which the tiles are laid and the smoothness of their inner walls, and the general plan of the system as regards turns, changes in slope, manholes, etc. The carrying capacity of a box drain depends upon the above-named factors and upon the shape of the box, the most advantageous shape, so far as capacity is concerned, being that in which the width is twice the depth of flow. The velocity should be high enough to prevent

silting, and the higher the velocity the smaller the cross-sectional area necessary to provide for a given discharge. The velocity is usually limited by the available fall, however, and it is quite the general thing, in the irrigated section, to have the drains run across the greatest slope, rather than with it. The smaller-sized tile should have a fall of at least 1 foot per thousand feet, and the larger sizes at least one-half foot per thousand feet.

Tile having an inside diameter of less than 4 inches should not be used, and even 4-inch tile should be used sparingly, usually at the extremities of small branches. Experience has shown that the use of tile less than 5 inches in diameter is not warranted by the comparative results and cost. The cost of trenching and laying is about the same for 4-inch as for 6-inch tile, while the latter has about three times the carrying capacity of the former. The 6-inch tile also presents a much larger surface to the surrounding soil and has more than double the area of bore, so that a given amount of silting represents a much less obstruction to the flow; also it is much easier to insert devices for clearing out the 6-inch line than is the case with the 4-inch one.

CHOICE OF TYPE OF DRAIN.

Both the open canal and the covered conduit are applicable to the drainage of irrigated lands. Each serves a purpose and under certain circumstances there is no question as to which to employ. There is, however, a zone in the scale of varying conditions in which the choice is not easily made. These conditions are worthy of special consideration.

The primary purpose of open canals is for main outlet systems or large laterals in which provision must be made for a considerable flow. Covered drains are for farm drainage proper. There are few reasons, save that of economy, why covered drains should not be used throughout, as they are more desirable in most respects; and when the problem as to which type to select arises, the question of desirability should be considered with that of economy. Open drains are unsightly and harbor obnoxious weeds; they occupy valuable space and often cut the land into inconvenient shapes, increasing the difficulties of cultivation and irrigation. Bridges, culverts, and flumes must be provided, and a constant watch must be kept lest irrigation streams find their way into the canals and do great damage to both the canals and adjacent lands, as well as waste the water. The maintenance cost of open canals is usually high in the irrigated sections, owing to the nature of the soil and to other causes.

The covered conduit usually requires no right of way and occupies no valuable land. If properly designed and laid it requires very

little maintenance. There is little danger of irrigation water getting into the drains, and the only way in which vegetation may do damage is by the entrance of water roots from certain trees and plants. This trouble may be avoided by keeping such trees as willows, cottonwoods, tamaracks, etc., well away from the drain lines, and by cutting away a narrow swath of such plants as the sugar beet from directly over the tile line. Black willows will send out roots to a distance of 200 feet and choke a drain, while sugar beets planted directly over a line will reach and obstruct a drain 5 feet deep. These roots penetrate only the disturbed soil of the trench, however, so it is necessary to remove but a narrow swath.

In deciding whether a large covered drain or an open canal shall be employed, it is necessary to calculate the original cost of each, taking account of all auxiliary and protective devices required, and then to add to each sum an amount large enough to give an annual return, at current rates, sufficient to cover the cost of maintenance. The consideration of the first cost alone gives very misleading results, as it has often been found that the difference in the cost of a very few years' maintenance would have more than paid the difference in first cost between the two types of drains. Thus, if a covered drainage system costs $1 per foot to construct, and the annual maintenance is 1 per cent of the first cost, 20 cents per foot must be added to yield an annual income of 1 cent per foot at 5 per cent interest, which makes the total cost $1.20 per foot. An open drain having the same capacity will cost about 30 cents per foot for excavation, 25 cents per foot for right of way, and 10 cents per foot for inlets, flumes, bridges, culverts, fences, etc. If the annual maintenance be taken at 10 per cent of the excavation cost, which is reasonable, 60 cents per foot must be added to yield an income of 3 cents per foot at 5 per cent, which gives a total of $1.25 per foot. The covered drain is to be preferred, therefore, even from the standpoint of actual cost; and when the other factors are considered there is no room for comparison between the two types.

Practice in the humid section is leaning more and more toward the covered drain, and tile having an inside diameter of 3 feet are not uncommon, while still larger sizes are sometimes employed. Until quite recently, very little tile over 12 inches in diameter had been used in the arid section. However, conservative estimates based on present prices and conditions show that it would be economical to use 20-inch tile, rather than the open canal of the same capacity; while improvement of methods, increase of land and crop values, and the decrease in the cost of materials that are now being witnessed, make it seem reasonable to predict that very shortly the eastern standards of practice will be adopted.

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LOCATION OF OPEN CANALS.

In considering the question of location, the specific purpose of the drain must be kept in mind. Outlet systems require treatment different from that given small canals or ditches intended to accomplish farm drainage directly. The former must usually follow the natural depressions and watercourses, while the latter must be located with strict regard to the source of the damaging water, as is the case with tile drains. For this reason the discussion of location of covered drains (pp. 18–24) may be understood to refer to the location of open farm drains as well.

It is generally a feasible and satisfactory practice to have small, open ditch outlet drains and laterals extend along the highways, as the roadway is thus drained and less right of way is required, since the spoil may be thrown into the roadway and crowned, making an excellent thoroughfare where roads may ordinarily be impassable during wet seasons. Figure 3 shows how this arrangement may be

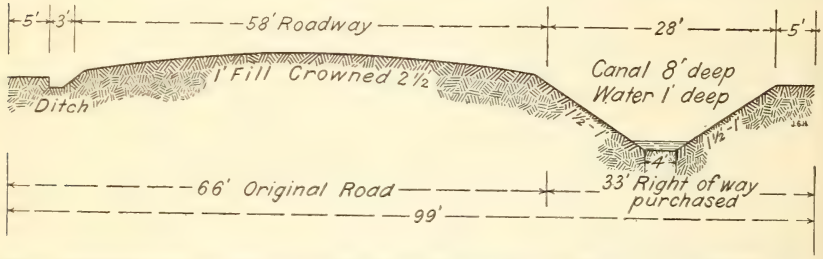

FIG. 3.—Illustrating how a canal may be built along a 4-rod road by purchasing a 2-rod right of way and placing all the spoil on the road.

effected, in the case of a 4-rod road, by the acquisition of a right of way 33 feet in width. A walk 5 feet in width is provided on either side, the drainage canal has the necessary depth and a desirable cross section, a small surface drain is provided at the left side of the road, and a roadway is afforded which is 58 feet in width and has a crowned surface rising 3½ feet above the general ground surface.

DEPTH AND LOCATION OF COVERED DRAINS.

One of the most important questions in drainage practice in the irrigated section is the proper depth at which to lay drains. Water often rises in soils, by capillary attraction, to a height of several feet above the free water level, and the presence of salts in solution increases the height of the rise and the rapidity of the movement. Evaporation takes place, and as a result the salt solution is concentrated at the upper limit of saturation. The height to which capillary water will rise depends upon the type of the soil, the wetness, the amount of foreign material in the soil, the amount of salts in the water, and the temperature. The rise may vary from a few inches

in gravel to a number of feet in fine, silty sand, or clay, soils; the rise may even extend to many feet in special soils containing a high percentage of gypsum or of calcium chlorid. Average soils show a range of from 1½ to 4 feet.

Plants in the arid region are unusually deep rooted, and they can not thrive unless the air and moisture conditions are properly balanced. Therefore, the plane of supersaturation must be kept below the root zone, and since this plane is several feet above the free water level it is necessary to give drains a considerable depth.

The presence of alkali salts complicates the problem of depth, for not only is the capillary rise of the water thus increased and expedited, but it is essential that the injurious salts themselves be kept down. It is highly important that a downward movement of the water in the root zone be maintained to offset the natural upward movement due to capillary attraction and evaporation. Owing to the presence of animal and worm burrows, cracks, root spaces, and other noncapillary openings, a great deal of water moves downward without coming into contact with salts; but the upward capillary movement is entirely through the capillary pores where the salts are confined. The natural tendency, therefore, is for the salts to move upward rather than downward. Drains should never be less than 5 feet deep, and experience has shown that depths of from 6 feet to 8 feet are much more efficient. The optimum depth for drains is that which will prevent fluctuations of the ground-water level within the root zone, and yet will keep capillary water within reach of the plant roots.

In determining proper depths the location of any stratum which is either more or less pervious than the adjacent soil is of great importance. This involves a careful study of the structure of the soil for considerable depths. It is quite possible to construct a well-arranged system of considerable depth which will be absolutely ineffective but which would have been highly effective if the depth had been increased less than 1 foot. Figure 4, a, illustrates an actual case of this kind. This system would have been successful if the tile had been laid as is indicated in b. The porous stratum carries water from higher lands, and where the stratum pinches out the water is forced to the surface, forming a bog. In the system as constructed, the tile was laid above the water-bearing stratum, in dry material, and the water continued to pass under it. Had the system been laid a foot deeper the stratum would have been cut and the flow intercepted.

Figure 5 shows a case where a tile line has been laid 5 feet deep in a soil underlain by a stiff, impervious clay at a depth of 6 feet. Here again the water passes under the drain and the system is a failure, though it could be made successful merely by deepening the drain.

In general, it may be said that the proper location of a drain depends upon the surface and subsurface topography, the nature of the soil, and the source of the damaging water. Subsurface conditions have more to do with the location of drains than does the sur-

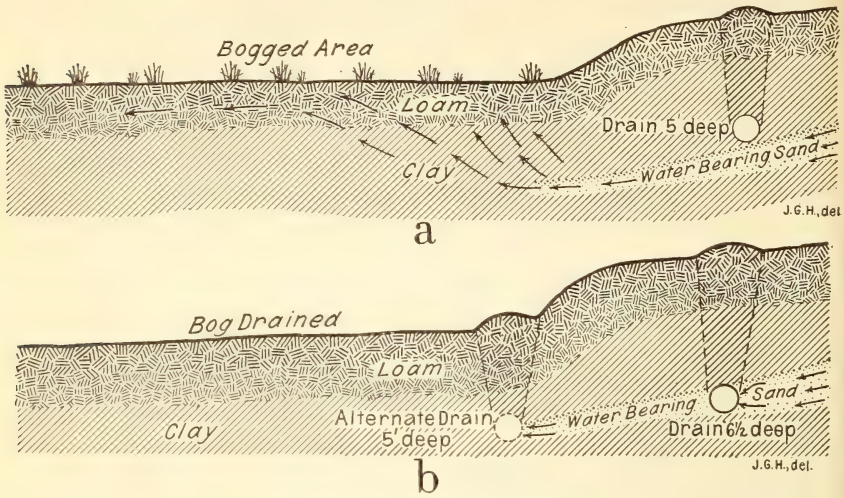

FIG. 4.—Illustrating importance of proper depth of tile: a, Drain ineffective owing to insufficient depth. The water passes through sand stratum under the tile, which is in dry clay. b, Two ways of making above system effective—by deepening drain 1 foot, or by changing the location so that line will cut through previous substratum, the depth remaining the same.

face topography, but most important of all is the source of the damaging water, since in many cases it is necessary to intercept this flow at the point of entrance to the tract. The question of location,

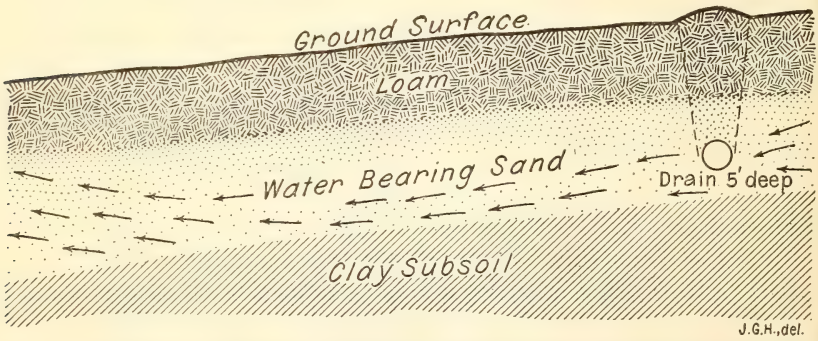

FIG. 5.—Section of water-logged tract in which attempt at drainage was unsuccessful owing to insufficient depth of drain. The trench should have been cut entirely through the water-bearing sand and the tile laid on the underlying clay.

however, must often be considered in connection with that of required depth. For instance, referring again to figure 4, b, it will readily be seen that a drain located at the change of slope will be fully as effective and more economical than one located on the top of the rise.

No general rules can be given as to the arrangement of drains on an irrigated tract. The proper locations have been predetermined by nature and it is necessary to study the conditions well in order to avoid mistakes. However, since the damaging water in the irrigated section moves underground, it is the subsurface rather than the surface conditions that must be studied. Few of the lines will be parallel, but economical features of design must often be sacrificed to an arrangement that will give the best drainage results.

PROTECTIVE DEVICES FOR OPEN CANALS.

Changes in the direction of a canal should be made by easy curves; otherwise one bank will be cut away while silt will be deposited at

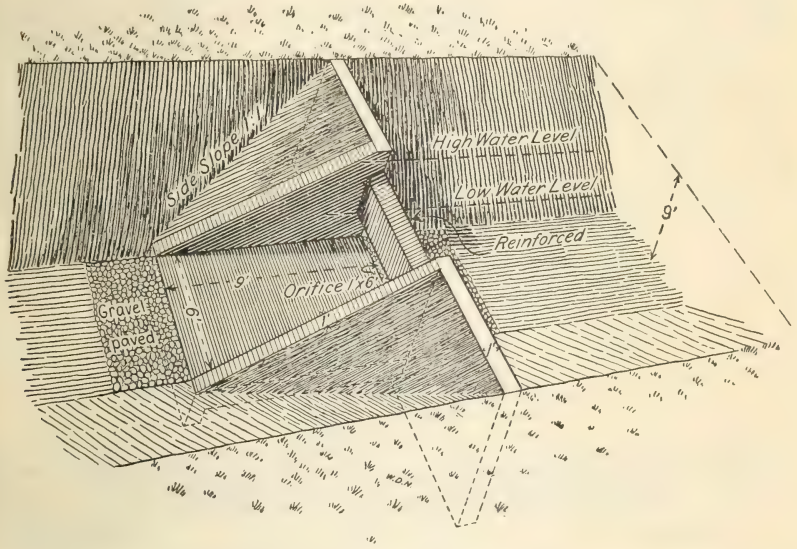

FIG. 6.—Concrete automatic regulating check for preventing erosion during periods of heavy discharge.

the opposite side of the channel. If a section of canal having a slope which causes erosion discharge into a section having less slope, silt will be deposited in the latter, due to the reduction in velocity, and the channel will become obstructed. Where the slope of a canal is such that the velocity will cause erosion, "drops" should be installed to lower the water from one level to another without injury to the channel.

CHECKS.

In some canals the usual flow is not sufficient to cause damage by erosion, but occasional floods increase the discharge to such an extent that the velocity is destructive. In such canals checks, designed to operate as spillways during high water but having an opening at the level of the canal bottom of sufficient size to pass the ordinary flow,

should be installed. Figure 6 illustrates such an automatic regulating check for use in a channel having a normal capacity of 8 second-feet,

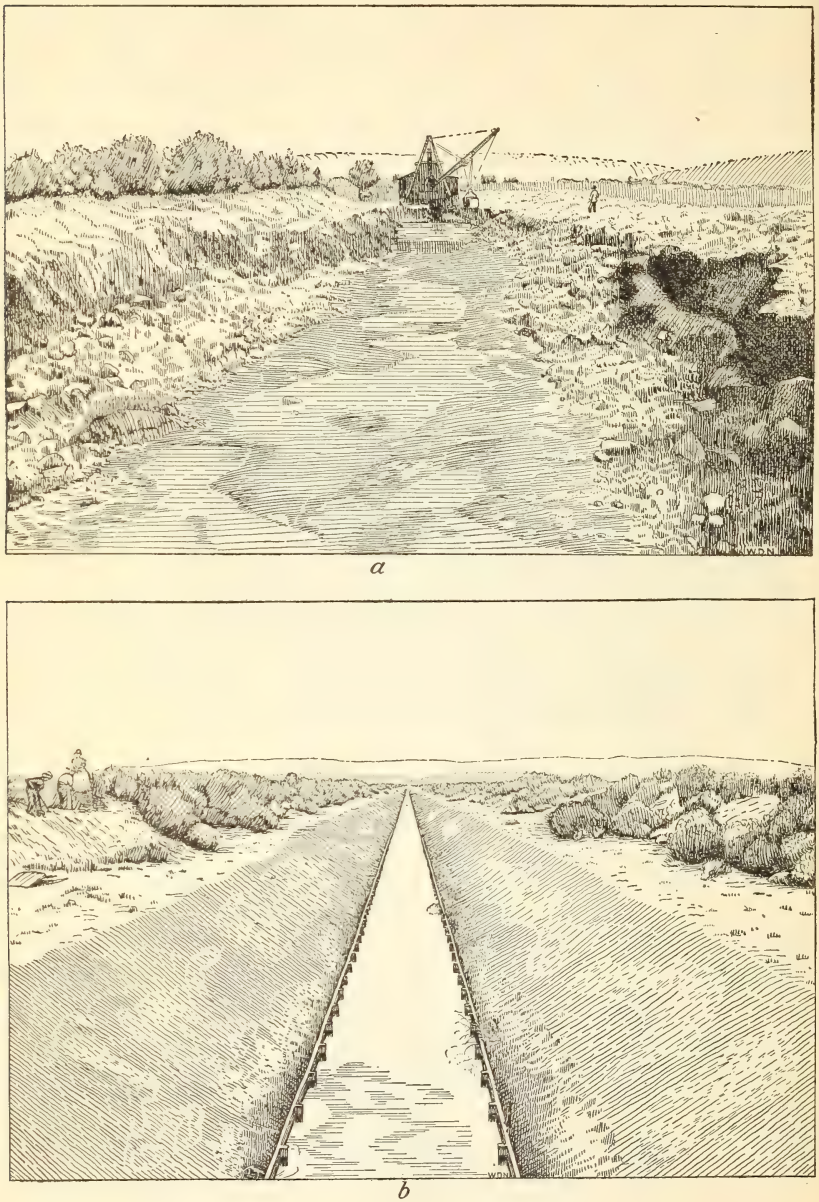

FIG. 7.—A canal in semifluid soil: *a*, before cunetting; *b*, after cunetting.

which will handle a discharge of 240 second-feet without danger of erosion.

CUNETTES.

If the soil be semifluid, so that the banks will not stand, it is necessary to install a cunette. This is done by driving timber piles at intervals of a few feet along both edges of the proposed bottom of the canal, and building in a plank waterway between the piles. Such a cunette supports the canal banks admirably. Figure 7 shows a canal in a semifluid soil, before and after cunetting.

ENTRANCE OF LATERAL DRAINS.

Lateral drains should be so located that at their outlets the water they discharge will be flowing in nearly the same direction as that in the main ditch. Grades of laterals should be adjusted to that of the main so as to prevent erosion. If the fall is so great that sufficiently flat grades can not be secured, drops should be installed. At points where waste water from irrigation enters the ditch, flumes or drops should be constructed to prevent the water from damaging the sides of the ditch and filling the channel with eroded material.

FLUMES AND BRIDGES.

Irrigation canals and ditches should be carried across drains in carefully constructed flumes or pipe lines of ample capacity, or, if their elevations are about the same, one stream must be siphoned under the other. Properly constructed bridges should be provided wherever crossings are necessary, as culverts are usually not satisfactory. At least 2 feet of clearance should be left between the surface of the water and the stringers of a bridge, so that floating weeds or other débris will not be caught and cause obstruction. No diversion dams or similar obstructions should be permitted in the channel.

PROTECTIVE DEVICES FOR COVERED DRAINS.

MANHOLES.

A change in direction of a line of tile should be made gradually by a smooth curve, or a manhole should be installed at the point of change. If the soil contains much fine sand, a combination manhole and sand trap should be located at such a point, as well as at every change from a steep to a lighter grade. Such a device serves as an observation well in which the flow may be seen and the general conditions of the system watched. It also serves as a settling basin for any sand or silt that may be carried by the drain, and if the trap is made to extend a foot or two below the drain, a chamber is formed in which a considerable amount of sediment is held until an opportunity is afforded for its removal. The manhole may also be provided with a surface inlet to enable the drain to take care of surface water, and, if desired, to provide for flushing the drain. As a manhole proper it provides a means for the operation of a root-cutting or drain-

cleaning device, operated by sewer rods. If it is expected that such work will be necessary the drains should be laid out in straight lines, with grades as uniform as possible; and a manhole should be provided at each junction, change in direction, change in slope from a steep to a lighter grade, and on straight sections at intervals not exceeding 500 feet.

On straight lines a manhole may be made long and narrow, but at a junction or turn it should be made square to facilitate the operation of rods and to prevent the sediment from being carried across the trap. A convenient size is 4 feet square. In constructing the manhole, brick or concrete is preferable, but lumber is often employed. When built of lumber, 2-inch material should be used. Figure 8 shows a simple type of manhole, constructed of lumber and so designed that earth pressure will maintain it in spite of the failure of the nails. Figure 18, page 23, illustrates the application of manholes. In most places the manhole should be provided with a bottom and it should always be fitted with a cover that may be locked down.

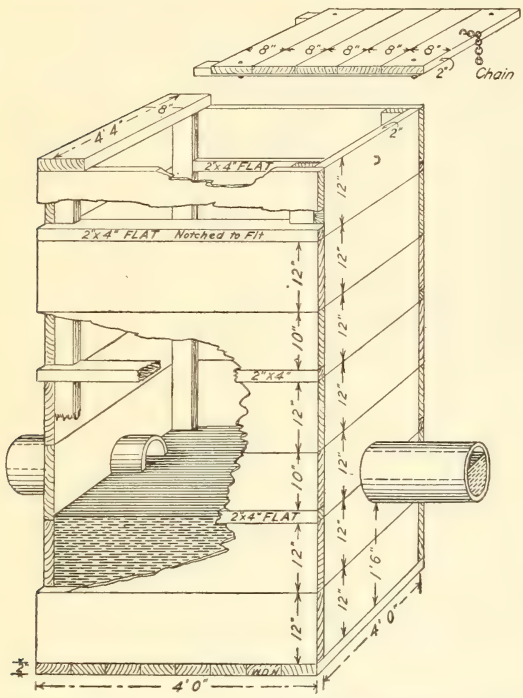

FIG. 8.—Combination manhole and sand trap with cover (Miller design), that does not depend upon nails to hold it together.

OBSERVATION WELLS.

If little sand be present, rendering sand traps unnecessary, it is still desirable that opportunity be afforded for observation of the flow at various points throughout the system. Nothing serves this purpose better than a vertical stack of large-sized tile, extending from a little above the surface of the ground to a foot or more below the tile line, and having holes cut in the lower length to accommodate the drain. Such a device is shown in figure 9. As may be seen, a small settling space is provided from which sediment may be removed from time to time by means of a telephone spoon. A cover should

always be provided. This device costs little and occupies but small space. If desired, the top section may be removed at any time, a cap provided, and cultivation carried on directly over the top. Such a device may also be installed between regular manholes, for inspection purposes. Figure 17, page 22, illustrates the application of observation wells.

SURFACE INLETS AND FLUSHING WELLS.

A vertical stack of tile is also useful as a surface inlet and flushing well. Figure 10 shows how it should be installed. The bottom

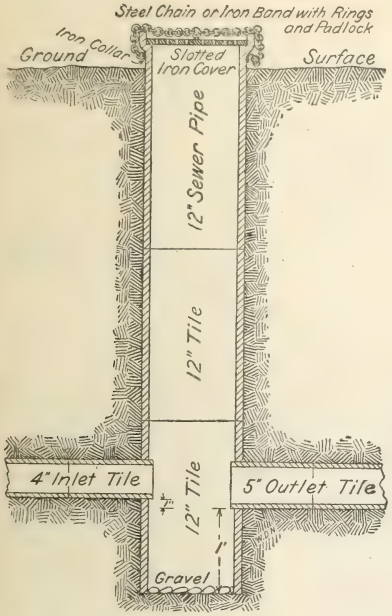

FIG. 9.—Observation well and sand trap constructed of tile.

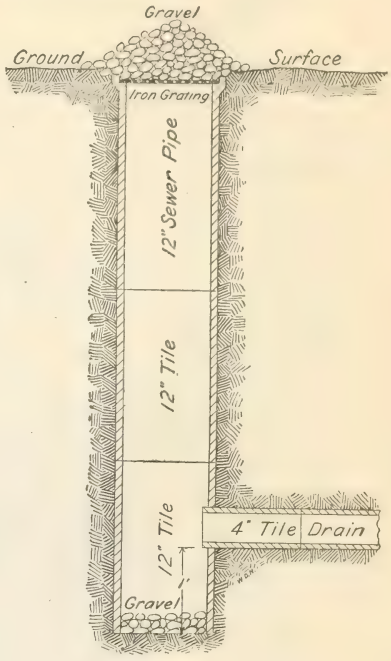

FIG. 10.—Standpipe, built of tile, for flushing drain or to act as surface inlet.

should be paved with coarse gravel and the top provided with an iron grating and a mound of gravel or crushed stone. Such an inlet should be installed wherever a drain crosses a depression or flat, so that the waste water or storm water may not pond for a sufficient length of time to puddle the soil or "burn" the crop. One of these should also be placed at the upper end of each branch line as is indicated in figure 17, page 22.

FLUMES.

Flumes should be provided for all canals and ditches that cross underdrains, and care should be taken to prevent large quantities of water from flowing across these drains, particularly during the first two seasons after the installation of the latter.

BULKHEADS.

A bulkhead should be constructed at the outlet of the underdrainage system to avoid injury from frost and caving of the banks at that point. This may be made of concrete, brick, or timber. Care should be taken that it has a good foundation, in order that it may not be undermined. Figure 11 shows a concrete bulkhead which may be easily and cheaply installed and which will give satisfactory service. A network of wires or small rods of copper or iron should be placed across the outlet to keep out small animals.

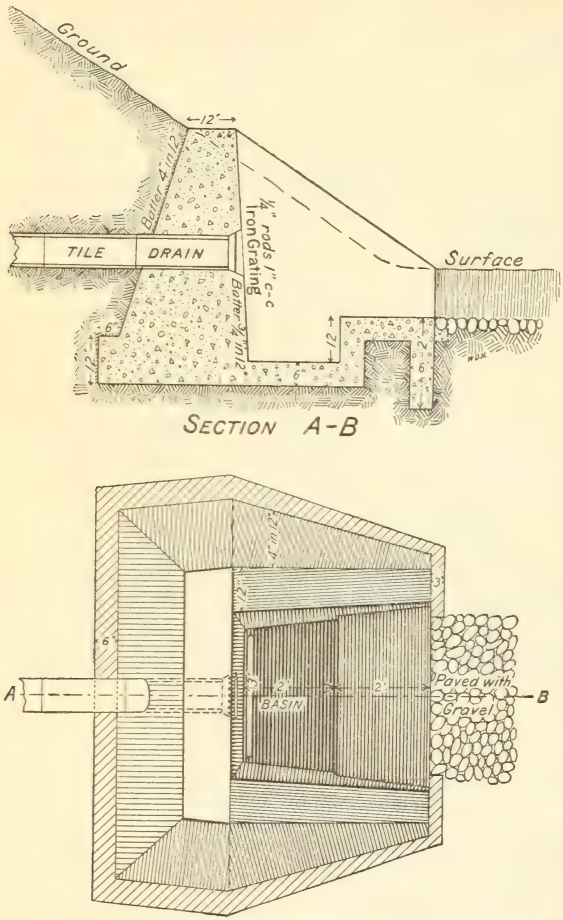

FIG. 11.—Concrete bulkhead for protection of outlet of tile-drainage system.

SOME TYPICAL PROBLEMS AND THEIR TREATMENT.

INTERCEPTION OF LATERAL SEEPAGE.

Figure 12 is a map and cross section of a typical case of waterlogging due to seepage from higher lands, to which the interception method of drainage should be applied. The damaging water is conducted through a pervious stratum that lies at a moderate depth, and owing to a change in slope from a steep to a lighter grade this water is forced to the surface.[1] The drain should be located at the change in slope, as shown, and should be run diagonally across

[1] The slopes of the land are indicated by lines drawn across the map, any one of which lines passes through points of the same elevation, this elevation being that shown on the line. These are called contour lines. The lines shown on the map are at 1-foot vertical intervals, and may be compared with the successive shore lines of a pond of water which is rising or falling 1 foot at a time. It is plain that the degree of slope of the land is indicated by the frequency of the contour lines, the latter being close together on steep land and spread apart on land of slight slope.

the slope and connected with an outlet drain. One of the commonest locations of seeped lands is this belt of comparatively level land at the foot of a steeper portion, and there is no place where drainage may be more economically applied. A single drain line will usually intercept the flow from outside sources, and the pervious stratum, being relieved of its water, serves as a drainage system to take care of the water applied to the tract itself. The pervious stratum may well be considered a great sheet drain.

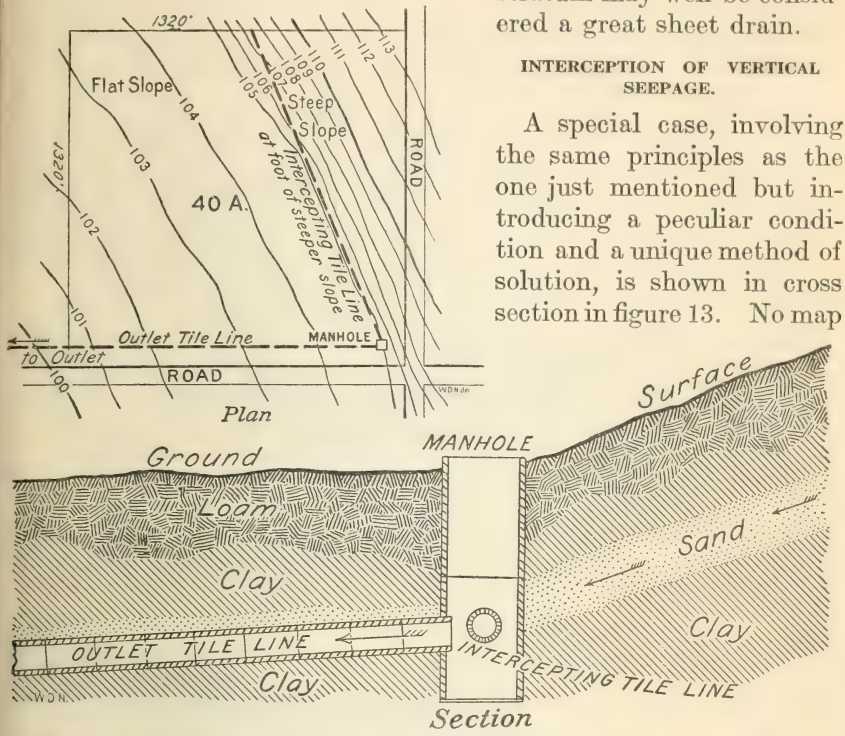

FIG. 12.—Plan and section showing typical case of water-logging due to seepage from higher land.

INTERCEPTION OF VERTICAL SEEPAGE.

A special case, involving the same principles as the one just mentioned but introducing a peculiar condition and a unique method of solution, is shown in cross section in figure 13. No map is given, as the surface topography is similar to that shown in figure 12, and the drains have the same location and depth. The water moves down the slope from higher lands through a very deep pervious stratum. At the change of slope the pressure forces the water to the surface. Owing to the considerable depth from which the water must rise, it is spread over a large area and there is little in the appearance of the ground surface to indicate its source. The condition may be relieved by a single drain, located as shown in figure 12, and connected by means of relief wells to the pervious substratum. The water rises in the relief wells, owing to its pressure, and flows out of the drains. This situation is not infrequently met with, and until subsurface conditions are thoroughly explored the problem appears baffling.

Ordinarily, a satisfactory relief well may be bored with an 8-inch post-hole auger. It should be cased with tile or pipe, or filled with

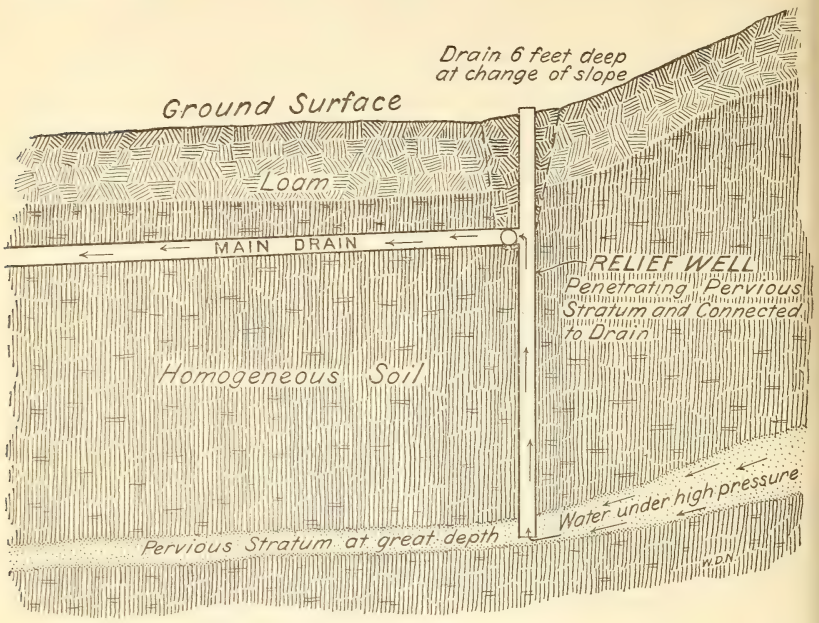

FIG. 13.—Section showing relief-well method applied to the drainage of lands receiving water from a deep pervious stratum.

coarse gravel. Relief wells in gravel, however, develop so much water that it is necessary to excavate a pit and build in a lumber or concrete box.

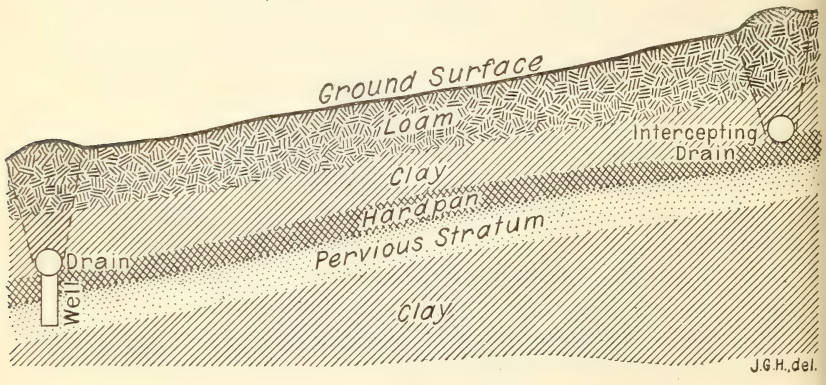

FIG. 14.—Section showing method of draining soils underlain by hardpan at a shallow depth by the use of relief wells. Intercepting drain cuts off seepage carried on the top of the hardpan.

DRAINAGE OF SOIL HAVING HARDPAN SUBSTRATUM.

Another case in which relief wells may contribute toward efficiency is shown in figure 14. In this case, which is frequently met with, a stratum of hardpan is found at a shallow depth, this being underlain

by a stratum of water-bearing material in which the water is generally under pressure. The hardpan is very difficult to penetrate with a trench, and the underlying material makes a poor bedding for tile. Moreover, the hardpan is practically impervious to water and to plant roots, so there is no need for deep drainage. The drain is laid on top of the hardpan and relief wells are bored through at frequent intervals, as shown in figure 14. The pressure causes an artesian flow which is carried away by the drain. Should there be seepage on top of the hardpan it may be intercepted at the upper edge of the tract.

DRAINAGE OF GRAVEL POCKETS.

Relief wells are especially useful in the drainage of soils underlain by gravel beds or pockets, particularly at the foot of benches, where the bottom land contains so much quicksand that it is difficult to lay a drain at the proper depth. Figure 15 shows the method of

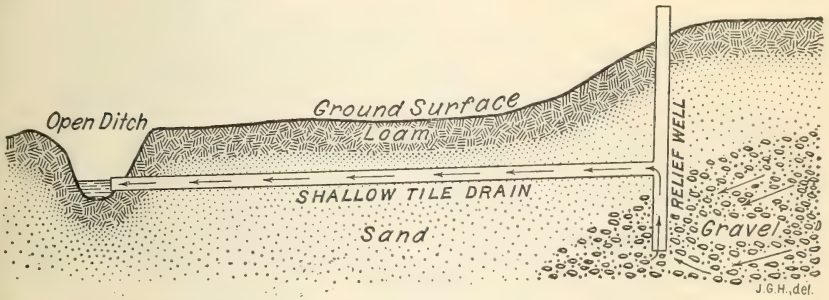

FIG. 15.—Section illustrating relief-well method applied to drainage of soils fed from gravel deposits.

application. The relief well should be sunk into the gravel. Enormous quantities of water are developed in this way; there is a case on record where a single well drained 100 acres of very wet land.

DRAINAGE OF SHALE KNOLLS.

Another application of the relief-well system is shown in figure 16 in which case the source of seepage is a buried shale knoll. The seepage is carried between the shale layers and is under pressure which is relieved by means of wells, these being connected to outlet drains.

APPLICATION OF THE UNIFORM SYSTEM.

There are some conditions where the uniform method of arranging the drains as used in the humid section is applicable. Among these is the case of a tract lying nearly level, having a fairly homogeneous soil or perhaps a substratum of sand at moderate depth, and receiving but little water from outside sources, the excess water being that due to the irrigation of the tract itself. The gridiron system, as shown in figure 17, is a most efficient plan under such conditions, the drains being placed from 200 to 450 feet apart. The latter figure

would apply to lands underlain by a sand stratum at from 4 to 6 feet below the surface. The drains should cut through this sand stratum, which itself thus becomes a great sheet drain. Under this arrangement three lines of tile to the 40-acre tract, or less than 100 feet of tile per acre, will drain fairly tough clay soil.

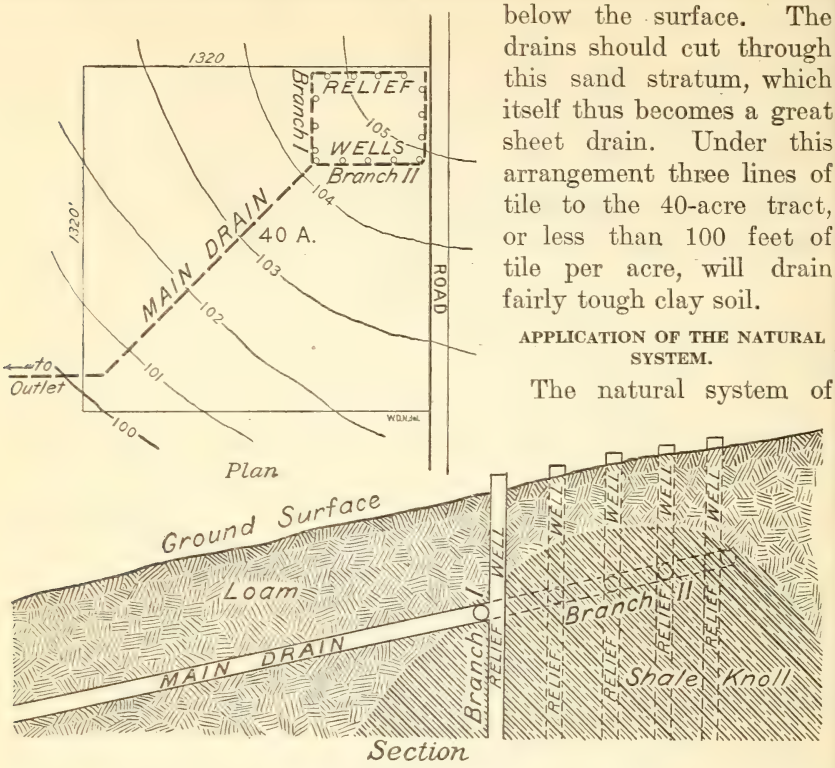

FIG. 16.—Plan and section showing method of draining where source of seepage is a buried shale knoll.

APPLICATION OF THE NATURAL SYSTEM.

The natural system of drainage is also applicable to irrigated lands. The principle involved in the application of this system is to assist the natural drainage and expedite its movement. To do this the drains are laid in the natural depressions and the ground water lowered in those locations, so that the movement of water toward the depressions is made more rapid. The system is especially applicable to lands underlain by gravel which occurs in undulating strata or beds.

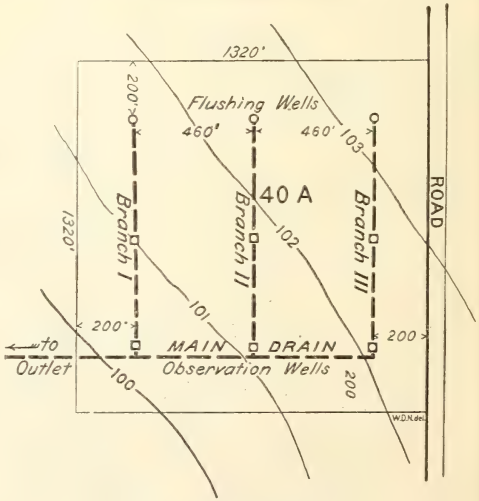

FIG. 17.—Sketch map showing application of a uniform system of drainage.

It has been found, however, that in the

irrigated region the seepage moves down the ridges more readily than down the depressions, so it is generally necessary to modify the drainage system by means of intercepting laterals cut through the ridges near the upper edge of the tract. These are indicated at *a*, *b*, *c*, *d*, *e*, and *f*, in figure 18.

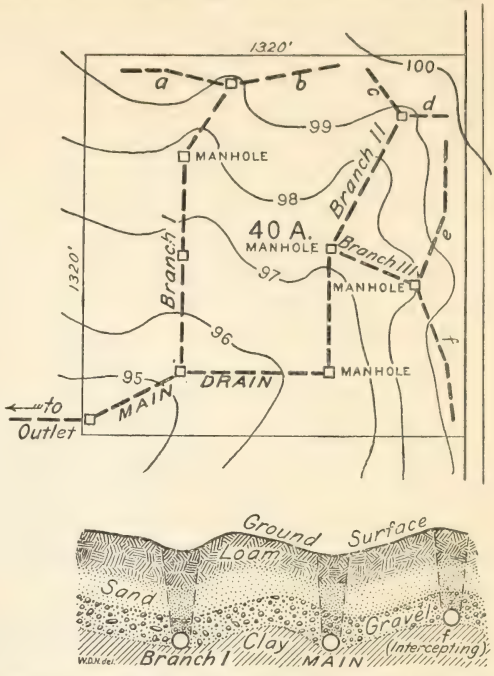

FIG. 18.—Plan and section illustrating application of natural system modified by intercepting laterals.

APPLICATION OF DOUBLE LINES.

If the depressions are wide and the pervious material does not extend under the soil in the depressions, it will be necessary to employ two lines, one on either side of the depression, cutting into the pervious material. However, if it is possible to completely intercept the seepage by means of laterals at the upper edge of the tract, it will be cheaper to construct a single line down the center of the depression. Figure 19 shows how a double-line system would be located.

OTHER SPECIAL CASES.

In some localities the soil is underlain at shallow depths by lava or other rock formations, and the problem of drainage is exceedingly

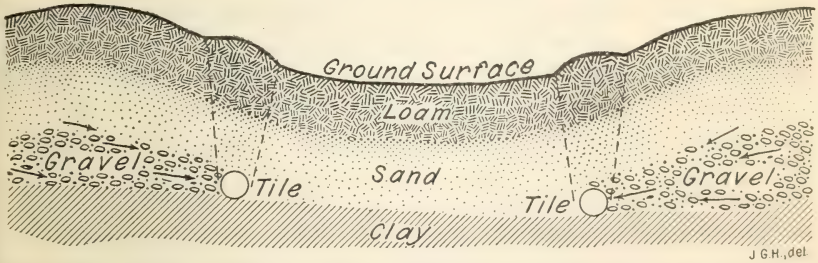

FIG. 19.—Cross section showing modification of natural system in which two lines of tile are employed, one on either side of the wide depression and cutting through the pervious layer at the line of pinching out. A single drain in the center of this depression would accomplish very little.

difficult. Often the formation is so stratified and shattered that the natural drainage seems to be very good. Water enters the spaces very readily, however, and the rock masses themselves absorb but

little so that the ground-water table rises very rapidly when irrigation is applied and soon creates a demand for drainage. The damaging water must be cut off as it leaves the rock formations and before it enters the soil, or it may be tapped by means of relief wells.

Another situation that presents difficulty is that in which the irrigation canals have been constructed in old watercourses and natural drainage channels. These channels are often higher than the surrounding lands, due to the fact that they have overflowed from time to time, and the soil adjacent to them is coarser than that at a distance. Seepage from the canals waterlogs the adjacent soil and causes alkali salts to appear at the surface. Waste water and seepage from irrigation of the land find their way to the depressions and form ponds, or swamp the farm lands. To remedy these conditions, drains must be constructed through the lower portions to carry off surface water, waste water, and seepage, and to provide an outlet for tile drains on the higher portions. Intercepting drains must also be constructed parallel with the irrigation canals, to catch the direct seepage. It is usually feasible to construct these in the borrow pits adjacent to the irrigation canals. The main outlet drainage canals should not be placed in such locations, however, as they would not then afford an outlet for tile systems nor take care of the water that reaches the depressions.

CONSTRUCTION OF DRAINS.

The soils of the arid region are usually semi-fluid when wet, due largely to the absence of humus, and the construction of drainage systems therefore often requires the exercise of considerable patience and ingenuity. Special methods and devices have been called for and special machinery has been needed to overcome these difficulties.

OPEN CANALS.

In the construction of open canals in the irrigated section it has been found that the use of teams and scrapers is generally not feasible, owing to the considerable depth that must be obtained and to the miry condition of the soil. Hand labor is equally out of the question, owing to the excessive cost. The most satisfactory method of handling the work is by means of some efficient excavating machine. A number of these machines have been developed, but few of them are suitable for work in the irrigated section. A discussion of the comparative merits of the different machines is not within the scope of this paper. In general, the choice of the type of machine should be left to the contractor or other party doing the work.

Construction work should always start at the outlet of the drain and proceed up the slope, so that the water developed will drain away.

The spoil should be placed well away from the channel and may be deposited on either or both sides. Openings in the spoil banks should be left wherever lateral or waste ditches are to enter. The contractor should be required to give the canal as true a form as possible, as irregularities are likely to become more pronounced. It is well to excavate a little below grade to allow for silting and spalling. If it is found impossible to give the banks the proper slope, owing to the bad condition of the soil, it is well to excavate in terraces and leave the final form to the action of the elements. As a rule it is not advisable to attempt to cut out a canal by means of water, but this has sometimes proved effective where the fall was sufficient.

Little clearing for right of way is required in the irrigated section and little rock is encountered. Rock and frost should be broken by means of dynamite before an attempt is made to use a bucket.

COVERED DRAINS.

In installing covered drains either hand labor or trenching machinery may be used. On small projects hand trenching is frequently cheaper, but on larger projects the machine generally can do the work more rapidly and economically. In either case methods and devices adapted to the nature of the soil and to other local conditions must be employed.

If hand labor is used it is necessary to operate with small gangs, never more than a half dozen men to the line, as the trench must be opened from top to bottom as rapidly as possible and the tile laid and blinded before caving takes place. The men must work as closely together as is practicable; and it is generally advisable to do rapid, systematic work for a short time or until a given length of drain is completed, and then to rest for a few minutes and be prepared for another vigorous attack. Each man should remove a spading and move backward. The man removing the last spading should also grade the trench bottom. He should not step on the finished bottom, and no one should stand near the edge of the trench. The tile should be laid at once and should be blinded by means of a few inches of earth caved from the edges of the trench. If the banks tend to cave off in large chunks or slabs it will be necessary to brace them apart with planks separated by stout crosspieces or by trench jacks.

A very troublesome condition is that in which the presence of a wet, pervious stratum near the bottom of the trench causes a lateral and upward movement of the soil in the bottom of the trench. In such a case it is necessary to provide a tight cribbing to shut out the oozing material. A design for such a cribbing is shown in figure 20. It consists of two heavy timbers, held apart by means of trench jacks, behind which is driven lumber sheeting properly matched and beveled at the lower ends to insure a tight fit. The sheeting may be

driven by means of a heavy maul and may be removed by a three-legged derrick and a special grabhook, as shown in the figure.

If the soil in the bottom of the completed trench be so soft that it will not support a man's weight, boards should be laid under the tile to keep them in line and on grade. For large-sized tile the planks should be built into a triangular trough; or, if conditions are exceedingly bad, piles should be driven and planks secured to them in the form of a cradle. Under such conditions it is often advisable to employ sewer pipe in place of drain tile, as the bells aid in keeping the line intact. Second-quality pipe is suitable and may generally be purchased at about the same cost as drain tile. Under ordinary conditions, however, the use of sewer seconds is not recommended, as the cost of freight and hauling is higher than for drain tile and the former are heavier and more difficult to handle. Also in stable ground it is necessary to dig out places for the bells, which considerably increases the cost of trenching.

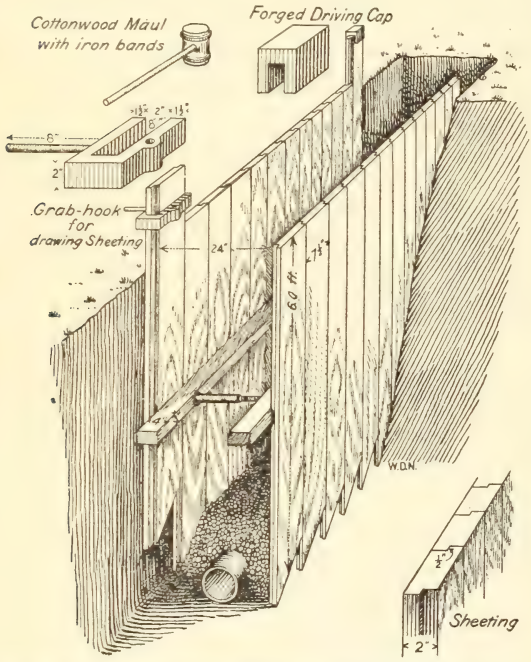

FIG. 20.—Method of sheeting trenches of moderate depth (Miller system).

The tile should be hauled and distributed in one operation and should be strung out end to end in a line about 10 feet to one side of the proposed trench, with an occasional length laid down to allow for breakage.

Lines and grades for drainage work should be carefully established by surveys. To obtain a guide for hand trenching, a cord or wire should be stretched along the ground at one edge of the proposed trench, and to afford a convenient method of determining the proper depth at all points grade planks should be set up at each 50-foot station, as shown in figure 21. These planks should all be of the same height above the proposed grade of the trench, so that a cord stretched over the center of the trench will be at a uniform height above grade.

A pole gauge of this length may then be used to establish the grade at each tile, as shown in the figure. To ascertain the height above ground at which each grade plank must be set, it is only necessary to subtract the calculated cut at that station from the length of the gauge pole used, say 7 or 8 feet. For machine trenching, poles should be erected at frequent stations and target arms set at a uniform height above grade upon which sights may be taken by the operator of the machine. Tile should be laid true to grade and in straight lines. No attempt should be made to judge grade by the water in the trench. It is easy to vary a foot from the proper grade in a short distance in this manner. Tile should be laid within a half inch of true grade under ordinary conditions, and it is possible to do even better than this.

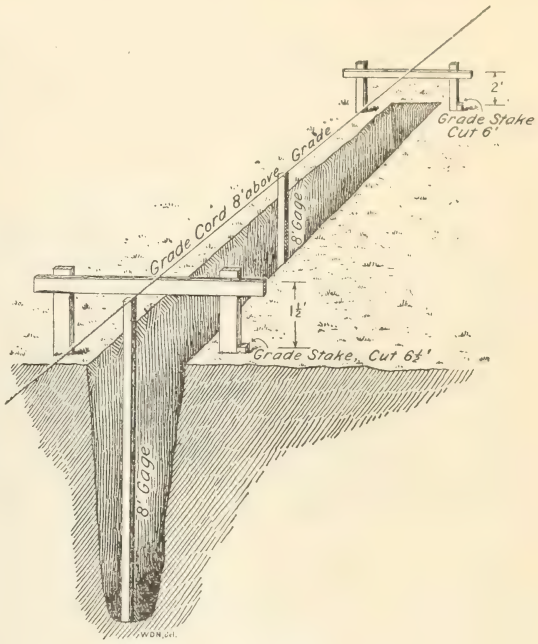

FIG. 21.—Method of establishing grade by means of cord and gauge.

In laying tile the joints should be placed as close as possible. If the soil be semifluid and contains much sand and silt, it will be necessary to provide some means of keeping the oozing material from entering the tile joints. Almost all of the water entering the tile lines makes its way through the joints, practically none entering through the walls of even the most porous tile, so the covering for the joints must provide for the ready passage of the water. Straw makes a very good filter when new, but it is likely to decompose and to form a sort of cement over the joints. Brush and willows are not satisfactory and render any subsequent removal of tile very difficult. Graded gravel, ranging from coarse sand to pebbles an inch in diameter, makes an excellent filter, but is not always available. Cinders also are satisfactory. Strips of burlap wrapped about the joints give good service. For genuine quicksand perhaps the best material is cheesecloth, which should be doubled once or twice and wrapped very carefully about the joint. This material soon disappears, but in the meantime the soil becomes compacted so that the purpose is served.

The more pervious material excavated should be placed adjacent to the tile. The backfilling may be done by means of a plow with three or more horses and a long pole evener, or by means of a scraper or "go-devil." All the spoil should be returned to the trench and should be banked over it so that future settling will not leave a depression over the drain.

Various types of trenching machinery, some of which are suitable for use on irrigated land, are on the market. The choice of machine may well be left with the contractor, however, and the question will not be discussed here.

MAINTENANCE.

If a canal is to retain its efficiency it must be well maintained. At least twice each year (more often if necessary) vegetation should be removed from the channel and banks, and such material as has fallen into the channel taken out. Any damaged places must be repaired to prevent further trouble. Tumbleweeds are a source of much difficulty, and it seems practically impossible to keep them out of drainage canals. They soon form serious obstructions and it is necessary to remove them at frequent intervals; this is generally done by men equipped with forks and rakes. Fortunately, these weeds generally disappear when drainage is accomplished. Perhaps the most difficult thing to deal with is "blow sand," which, during a high wind, may completely obstruct a canal in a few hours. From the very nature of the conditions maintenance is difficult and costly, and it follows that every endeavor should be made, during construction, to reduce the amount of maintenance necessary. When it is realized that the annual cost of maintaining open canals is often 10 per cent of the first cost, the need for correct design and careful construction is apparent.

A properly designed and well-constructed tile system requires little maintenance. Obstructions in the line, and vegetation that may develop dangerous water roots, must be removed. Holes and depressions in the backfilling must be filled and the burrowing of animals prevented.

A number of types of tile-cleaning devices have been developed. These are useful during construction in keeping the suspended matter in movement until the flow of water is large enough to create sufficient velocity to carry the material along. After the system is put in operation they may be used to clean out water roots that may have penetrated the tile line through the joints, or to clear the line of obstructions caused by sand or silt. One of these devices is in the nature of an auger, while another kind is built like a small hoe. For the removal of roots an apparatus involving a spiral cutter is used, or better still, a sort of wire brush. The latter is also useful in removing other obstructions and may easily be made by wrapping a piece of

leather belting around a cylindrical wooden rod, first having driven the belting full of nails of such length that the outside diameter of the completed brush is somewhat smaller than the inside diameter of the tile to be cleaned. These devices may be operated most conveniently by means of jointed sewer rods. The latter are made up in 3 or 4 foot sections which are fitted with couplings so arranged that they may be joined when two sections are placed at right angles, and are locked together when the two sections are in line. Working in a manhole 4 feet square, a man can easily put together and operate several hundred feet of rod in a tile line. Figure 22 shows a set of sewer rods and cleaning devices that have given satisfaction in operation.

SUBSEQUENT TREATMENT OF LAND.

While drainage is essential to the reclamation of water-logged and alkali lands, subsequent work is necessary for the complete redemp-

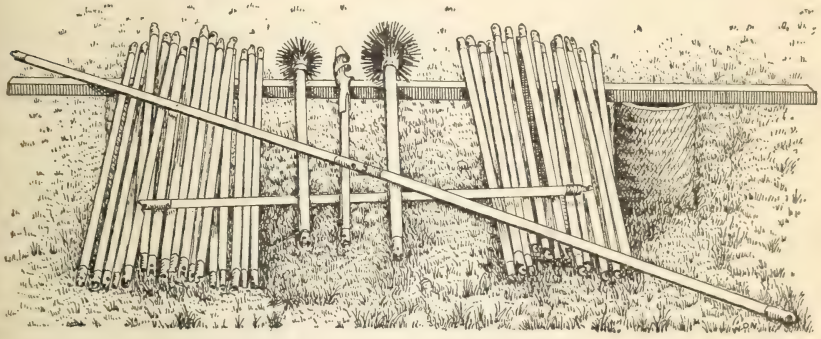

FIG. 22.—Sewer rods and tile-cleaning devices.

tion of the soil. The alkali salts which may have accumulated in the upper portions of the soil must be removed and the proper physical condition of the soil itself must be restored. Humus must be increased and it will be necessary that steps be taken to reduce evaporation, to maintain a downward movement of the salt solution, and to prevent any future rise of the latter.

The salts, being soluble, will usually be removed in time by the action of ordinary precipitation, and this latter is always an important factor in the subsequent treatment; however, the natural method is often too slow and is sometimes entirely ineffective, due to the fact that the precipitation is sufficient to saturate only a foot or so of the soil, and the excessive evaporation immediately returns the salts to the surface.

If expedition be desired, a good-sized stream of irrigation water should be turned on the land and allowed to percolate through the soil as rapidly as possible. This is best accomplished by diking the

land into checks and ponding the water as deeply as possible; each check should have as large an area as the slope of the ground and the amount of available water will permit. In no case should an attempt be made to flush the salts from the surface. They must be leached out and carried in solution downward to the underground reservoir. The desirability of using large checks and liberal quantities of water is due to the fact that capillary attraction is equally effective in all directions, and it is necessary to offset the tendency of the salts to move laterally in the soil and reappear on a higher or drier portion of the tract. For this reason it is required in flooding to make sure that all the surface is covered, even if knolls and ridges must first be leveled. It is generally advisable to thoroughly cultivate a field before the leaching process, but in some cases it has been found to be more satisfactory to flood first and then to cultivate as soon afterward as possible. If the subsoil be so impervious that the leaching water does not percolate readily, it may be necessary to resort to subsoiling or blasting.

The quantity of salts removed by the leaching process is surprisingly large when considered as a total. It is not unusual to find a soil containing an average of 1 per cent of its dry weight in salts. Taking the average dry weight of the soil at 100 pounds per cubic foot and the depth of drainage at 6 feet, each cubic foot of the soil contains 1 pound of salts, and each 6-foot column of soil, 1 foot square, contains 6 pounds of salts. This amounts to 261,360 pounds, or over 130 tons of salts per acre, in a depth of 6 feet. For a 160-acre farm, this would amount to nearly 21,000 tons of salts.

Analyses show that the quantity of salts in the upper 6 feet of soil may be reduced 50 per cent by one flooding. But the discharge of $\frac{1}{4}$ cubic foot per second of water containing 1 per cent of salts, which is much higher than the average, would represent only 2,470 tons of salts per annum, and this takes no account of salts contributed to the tract by the irrigation water. From this it is evident that only a small portion of the salts is carried away by the drains and that by far the larger portion is leached into the underdrainage and redistributed below the drainage depth. This is a desirable condition, for it means that the mineral plant foods, which are also soluble in water, are not removed from the tract and wasted, but are left within reach of plant roots. It also means that the drainage water is sufficiently free from harmful salts to be useful for irrigation purposes. Indeed, conservation of the irrigation supply is being effected by applying to one tract water that has been drained from another, and in a few cases the drainage water is pumped back for the irrigation of the reclaimed tract itself.

The land should be cropped as soon as possible after reclamation; some crop which will shade the ground is preferable. If possible the

plants should be alkali resistant. It must be kept in mind that the salts are brought to the surface of the ground, in solution, by the capillary action of the soil particles and that they are deposited upon the surface when the solution is evaporated; hence the advisability of planting shading crops which reduce the evaporation. Artificial or soil mulches accomplish the same thing, and if shading crops are not planted, the soil should be kept well stirred. Subsoiling, besides assisting the leaching waters to percolate to the drains, breaks up the capillary columns and retards the upward movement of salts.

Alfalfa hay is a staple crop everywhere in the irrigated region. The alfalfa plant transpires a great deal of water, shades the ground surface well, gathers nitrogen, which is usually deficient in reclaimed alkali soils, and provides a liberal amount of humus when plowed under. It has been shown by Thomas H. Kearney [1] that a mature plant withstands well the action of salts, but unfortunately the young plants are very tender and germination of seed is next to impossible if there be much salt present. Sweet clover, also, is resistant to alkali and possesses all the good qualities of alfalfa, except as to its value as hay. It makes good forage if kept pastured down and should be employed at first if the more valuable crops can not be grown. Bermuda grass is fairly resistant and makes a good pasture, but its use can not be recommended, as it is more difficult to get rid of it than to reclaim the land from an alkali condition.

Mr. Kearney has also shown that the sorghums, Kafir corn, milo maize, etc., are adapted to use on reclaimed lands. Field corn is fairly resistant in most sections. Of the small grains, barley is the most resistant; but it has been found that when newly reclaimed tracts are devoted to grain it should be planted in the fall, so that the plants may become sturdy before the salts are brought to the surface by excessive evaporation in the spring. Grain does not afford much shading and is of little benefit in reclamation beyond the value of the stubble as a source of humus when plowed under.

WHAT DRAINAGE ACCOMPLISHES.

As a result of draining, excess water, whether it be from precipitation, waste or irrigation water, or seepage, is removed from the soil and the ground-water table is permanently lowered. Fluctuations of the ground-water table are more injurious to plant life than is a permanently high-water table and, within certain limits, drainage prevents such fluctuations.

The removal of the excess water allows air to be drawn into the soil spaces and the proper equilibrium between air and moisture is thus maintained and the soil is made warmer. As a result of this, bacterial activity is increased and more plant food is produced. Moreover,

[1] U. S. Dept. Agr., Farmers' Bul. 446.

the root depth is increased so that both the available plant-food supply and the available moisture are increased by drainage.

The downward movement of water through the soil leaches out the excess of harmful salts, and this is one of the most important functions of drainage in the irrigated section. The movement of water also develops the pores of the soil, so that the physical character of the latter is improved.

Drained lands may be plowed earlier than undrained lands; thus the season is made both earlier and longer. An indirect result of this, which is of great importance in some localities, is that most of the irrigation may be done earlier than is usual and before the water supply becomes reduced. Moreover, drained lands require less irrigation water than undrained lands, and the water discharged by the drains may be employed for the irrigation of other areas, so that drainage practically increases the available irrigation supply.

Drainage performs an educational function in that it causes men to consider the use of water, to realize the vast difference between scientific irrigation and mere "watering," and to improve their methods of irrigation, resulting in a reduction in the amount of water used and in the subjugation of additional arid lands.

Drainage improves the public highways, railway roadbeds, and power lines, as well as telegraph and telephone lines. It increases the stability of buildings and structures and serves directly and indirectly to promote health and economic conditions in many ways.

COST OF DRAINING.

A distinction must first be made between farm drainage and outlet systems. The latter are intended only to afford outlet facilities to farm drainage systems and are rarely designed to accomplish drainage directly. Farm drainage systems are designed upon the supposition that natural drainage outlets exist or that artificial outlets will be available. Manifestly, it is impossible to build an outlet system that will not accomplish some drainage directly, and this, of course, reduces the cost of farm drainage in the vicinity.

The cost of outlet drainage systems varies from about $3 per acre to as much as $15 per acre. In the latter case very little farm drainage will be necessary, and the system may prove more economical than one costing much less but requiring more farm drainage.

The cost of draining ordinary-sized farms having an average soil that is neither so hard as to require picking nor so soft that extreme trenching difficulties will be encountered, will range from $10 per acre to $20 per acre with the average between $14 and $15 per acre. If hardpan be present or if the soil is so finely divided and so wet as to be fluxible, the cost will run up to $50 per acre and even more if much sheeting is required. In a few special cases, drainage of small

tracts in the midst of unreclaimed lands has cost between $75 and $100 per acre, but these costs represent situations that would not be encountered in regular operations.

In regard to costs per unit of length of drain it may be said that clay tile drains range in cost from about one-half cent per inch of inside diameter per foot of length in the smallest sizes, to about 2 cents per inch of inside diameter per foot of length in the larger sizes. Hand trenching for tile up to 12 inches in diameter under ordinary conditions ranges in cost from 7 to 15 cents per linear foot for an average depth of 6 feet, while trenching in fluxible or hard material will run up to 25 cents per foot. Rock work would, of course, be higher. When sheeting is required the work will cost 50 cents per linear foot and upward. Machine trenching is usually cheaper, there having been some jobs of 5-foot trenching taken as low as 4 cents per linear foot. As a rule, however, machine trenching costs at least $1 per rod for average soils and depths.

COOPERATIVE DRAINAGE.

The unit cost of drainage decreases as the size of the tract increases. This is partly due to the fact that a system installed on a small tract receives water from without the boundaries of the tract, and accomplishes more or less complete drainage over a considerable area. Furthermore, the unit costs of all materials and operations are less on the larger projects, and the required capacity of the drains becomes relatively smaller as the unit becomes larger. Economy demands that tracts as large as possible be handled as units, and, where the land is owned by a number of persons, it is necessary that some sort of cooperation be effected. Cooperation by mutual agreement is usually difficult and sometimes impossible to secure, owing to an unprogressive spirit among some of the landowners. However, the legislatures of practically all the Western States have provided laws by means of which cooperative work may be done. In general, these laws provide for the formation of drainage districts and for their government, prescribe their powers and privileges, and outline the duties of their officers. The direction of the business of a drainage district is in the hands of a board of drainage commissioners who are either elected by the freeholders in the district or are appointed by the county commissioners or the district court, depending upon which is the recognized authority in the matter of forming drainage districts. The district is granted the right of eminent domain, and bonds may be sold to pay for the construction work. Contracts may be let and provision is made for the equitable distribution of the cost of the work. The county officers are empowered to collect assessments. The construction work is done under the direction of an engineer appointed by the commissioners.

The usual procedure is to present a petition to the court or board, stating that the lands are in need of drainage and that the benefits of reclamation will exceed the sum of the damages caused and the cost of the work. Hearings or elections are held after due notice has been given, and the district is organized as a legal institution. In most States the organization of such districts is so easily effected, and operation under the law so comparatively simple, that it is advisable to make use of this means of carrying out the work.

CONCLUSION.

That the drainage of agricultural lands is an important factor in the future development of the irrigated section is shown in the alarming proportion of the lands that have been brought under irrigation which are now unproductive by reason of water-logging and alkali. The reclamation of these lands can easily and economically be effected by drainage, followed by proper cultivation, cropping, and irrigation.

The methods to be employed in draining have been described and the need for careful study of the subsurface conditions before starting the work has been emphasized.

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